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EXAMINER	
TRIEU, THAI BA	

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3748	

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Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Office Action Summary	Application No. 10/554,160	Applicant(s) BAUER ET AL.	
	Examiner Thai-Ba Trieu	Art Unit 3748	

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) OR THIRTY (30) DAYS, WHICHEVER IS LONGER, FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☒ Responsive to communication(s) filed on 21 October 2005.

2a)☐ This action is **FINAL**. 2b)☒ This action is non-final.

3)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

4)☒ Claim(s) 24-46 is/are pending in the application.

4a) Of the above claim(s) _____ is/are withdrawn from consideration.

5)☐ Claim(s) _____ is/are allowed.

6)☒ Claim(s) 24-46 is/are rejected.

7)☐ Claim(s) _____ is/are objected to.

8)☐ Claim(s) _____ are subject to restriction and/or election requirement.

Application Papers

9)☐ The specification is objected to by the Examiner.

10)☒ The drawing(s) filed on 21 October 2005 is/are: a)☐ accepted or b)☒ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

11)☐ The oath or declaration is objected to by the Examiner. Note the attached Office Action or form PTO-152.

Priority under 35 U.S.C. § 119

12)☒ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

a)☒ All b)☐ Some * c)☐ None of:

1.☒ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. _____.

3.☒ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

* See the attached detailed Office action for a list of the certified copies not received.

Attachment(s)

1) ☒ Notice of References Cited (PTO-892)

2) ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)

3) ☒ Information Disclosure Statement(s) (PTO/SB/08) Paper No(s)/Mail Date 10/21/2005.

4) ☐ Interview Summary (PTO-413) Paper No(s)/Mail Date. _____ .

5) ☐ Notice of Informal Patent Application

6) ☐ Other: _____.

DETAILED ACTION

The Preliminary Amendment filed on October 21, 2005 is acknowledged. Claims 1-23 were cancelled; and claims 24-46 were newly added.

Priority

Receipt is acknowledged of papers submitted under 35 U.S.C. 119(a)-(d), which papers have been placed of record in the file.

Claim Rejections - 35 USC § 112

The following is a quotation of the second paragraph of 35 U.S.C. 112:

> The specification shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the applicant regards as his invention.

Claims 24 and its dependent claims 25-36; and claim 37 and its dependent claims 38-46 are rejected under 35 U.S.C. 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention. Specifically,

- In claim 24, line 9, the recitation of "so that this can be taken account" renders the claim indefinite since it is not clear that to which element/component is the word "this" to be referenced? Under which condition "this" can be taken account, and under which condition "this" cannot be taken account within the framework of regulating the induction gas temperature. Applicants are required to identify this element/component and the condition for "this", or to revise the claimed limitation.

- In claim 24, line 10, the recitation of “the framework of regulating the induction gas temperature” renders the claim indefinite since it is not clear that to which framework is to be referenced in order that the induction gas temperature is to be regulated? Applicants are required to identify the framework is used to regulate the induction gas temperature, or to revise the claimed limitation.

- In claim 29, line 4, the recitation of “an induction gas temperature can be set or regulated by influenced through flow through the exhaust gas cooler” renders the claim indefinite since it is not clear that under which condition an induction gas temperature can be set or regulated, and under which condition an induction gas temperature cannot be set or regulated by influenced through flow through the exhaust gas cooler. Applicants are required to identify the condition for an induction gas temperature, or to revise the claimed limitation.

- In claim 29, line 5, the recitations of “taking account measured values or values determined on the basis of technical models” renders the claim indefinite since it is not clear that which models are to be considered as technical models to measure/determine values? And what does the basis means? Applicants are required to define the basis and the technical models, or to revise the claim limitations.

- In claim 32, lines 2-3, the recitation of “the exhaust gas cooler being designed as an engine or transmission oil heat exchanger repectively” renders the claim indefinite since it is not clear that how can the exhaust gas cooler be designed as an engine or transmission oil heat exchanger? Applicants are required to clarify the way to design

the exhaust gas cooler to become an engine or transmission oil heat exchanger respectively, or to revise the claim limitations.

- In claim 33, line 2, the recitations of "technical models" renders the claim indefinite since it is not clear that which models are to be considered as technical models? Applicants are required to define the basis and the technical models, or to revise the claim limitation.

- In claim 37, line 6, the recitation of "so it can be taken into account" renders the claim indefinite since it is not clear that to which element/component is the word "it" to be referenced? Under which condition "it" can be taken account, and under which condition "it" cannot be taken account within the framework of regulating the induction gas temperature. Applicants are required to identify this element/component and the condition for "it", or to revise the claimed limitation.

- In claim 37, line 7, the recitation of "the framework of regulating the induction gas temperature" renders the claim indefinite since it is not clear that to which framework is to be referenced in order that the induction gas temperature is to be regulated? Applicants are required to identify the framework is used to regulate the induction gas temperature, or to revise the claimed limitation.

- In claim 38, lines 2-3, the recitation of "an earlier combustion cycle" renders the claim indefinite since it is not clear that to which cycle is used to compared with in order that a cycle can be recognized as an earlier combustion cycle? Applicants are required to identify which cycle being earlier/former or which one is the latter, or to revise the claimed limitation.

Claim Rejections - 35 USC § 103

The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

Claims 24-28, 33, 37-38, 40-41, and 43-44 are rejected under 35 U.S.C. 103(a) as being unpatentable over Wild et al. (Patent Number 6,352,065 B1), in view of Fujimoto et al. (Patent Number 4,485,625).

Wild discloses a system for influencing an induction gas temperature in a combustion chamber of an internal combustion engine, comprising:

a compression device (102) to compress induced fresh air and the fresh air having a first temperature before compression (tu);

an expansion device (103) that causes an expansion of the compressed induced fresh air, with the compressed and subsequently expanded fresh air having a second temperature (ts) greater than the first temperature (tu); and

wherein an exhaust gas recirculation device (Not Numbered, via valve 107) is provided to feed exhaust gas from an earlier combustion cycle to fresh air or to a mixture featuring fresh air, in order to provide an air/fuel/exhaust gas mixture with an advantageous energy level for combustion after injection of fuel;

wherein the compression device is a compressor (102) (See Figure 1);

wherein the expansion is performed on a throttle valve (103) (See Figure 1);

wherein the measured values or the values determined in accordance with technical models are assigned to at least one of the variables selected from the group consisting of: exhaust gas temperature, recirculated exhaust gas mass (mp_agr), recirculated exhaust gas quantity, air/fuel temperature (mp_tev), air/fuel mass, air/fuel quantity (mp_fg), induction gas temperature (ts), induction gas mass (mp_hfm), induction gas quantity (VS), coolant temperature, oil temperature of the coolant, oil flowing through the exhaust gas cooler, coolant mass, oil mass, coolant quantity, oil quantity of the coolant, and oil flowing through the exhaust gas cooler (See Figure 1, and column 8, lines 20-67 and Column 9, lines 1-5);

However, Wild fails to disclose a temperature sensor, and an exhaust gas turbocharger.

Fujimoto teaches that it is conventional in the art of controlling internal combustion engine, to utilize a temperature sensor (18) to record the second temperature that is arranged in the direction of flow of the fuel/air with reference to the expansion device so that this can be taken into account within the framework of regulating the induction gas temperature (See Figure 1); and the compression device being an exhaust gas turbocharger (4) (See Figure 1).

It would has been obvious to one having ordinary skill in the art at that time the invention was made, to have utilized a temperature sensor, and an exhaust gas turbocharger, to record the temperature and to provide an alternative arrangement design for an internal combustion engine with a turbocharger for the Wild device.

Note that the recitation of “in order to provide an air/fuel/exhaust gas mixture with an advantageous energy level for combustion after injection of fuel.” is considered as the functional language. Wild discloses all the structural components of an engine system, which are read on those of the instant invention. Therefore, the Wild system is capable of performing the same desired functions as the instant invention having been claimed in claim 25.

Claims 29-33, 39, and 42 are rejected under 35 U.S.C. 103(a) as being unpatentable over Wild et al. (Patent Number 6,352,065 B1), in view of Fujimoto et al. (Patent Number 4,485,625), and further in view of Yahata et al. (Patent Number 6,826,903 B2).

The modified Wild discloses the invention as recited above; however, fails to disclose an exhaust gas cooler; a coolant-setting valve; and an exhaust gas cooler being arranged in a separate heat exchanger circuit; and an exhaust gas cooler being designed as an engine or transmission oil heat exchanger respectively.

Yahata teaches that it is conventional in the art an exhaust gas recirculation system having a cooler, to utilize at least one heat exchanger operating as an exhaust gas cooler (6) is provided for reducing the temperature of the re-circulated exhaust gas and a coolant setting valve (63) being provided so that an induction gas temperature can be set or regulated by influencing the coolant through-flow through the exhaust gas cooler taking into account measured values or values determined on the basis of

technical models; and an exhaust gas cooler being arranged in a separate heat exchanger circuit; and an exhaust gas cooler being designed as an engine or transmission oil heat exchanger respectively (See 1, 8, 10, 12, 14, 16, 18, 20, Column 3, lines 57-67, Column 4, lines 1-50).

It would has been obvious to one having ordinary skill in the art at that time the invention was made, to have utilized an exhaust gas cooler; a coolant-setting valve; and an exhaust gas cooler being arranged in a separate heat exchanger circuit, and an exhaust gas cooler being designed as an engine or transmission oil heat exchanger respectively, as taught by Yahata, to improve efficiency, of the modified Wild device.

Claim 34 is rejected under 35 U.S.C. 103(a) as being unpatentable over Wild et al. (Patent Number 6,352,065 B1), in view of Fujimoto et al. (Patent Number 4,485,625), and further in view of Treinies et al. (Patent Number 5,974,870).

The modified Wild discloses the invention as recited above; and further discloses a temperature sensor (18) to record the air/fuel temperature (See Figure 1 of Fujimoto), an air mass or quantity measurement device (via 101) respectively to record the air/fuel mass or quantity, and an exhaust gas mass or quantity measuring device (via 107) to record the exhaust gas mass or quantity are provided (See Figure 1 of Wild).

However, the modified Wild device fails to disclose a temperature sensor.

Treinies teaches that it is conventional in the art of determining fresh air mass flow into an internal combustion engine having an EGR system, to utilize a temperature

sensor (32) to record the exhaust gas temperature at the engine exhaust (See Figure 1).

It would has been obvious to one having ordinary skill in the art at that time the invention was made, to have utilized a temperature sensor, as taught by Treinies, to improve the efficiency of the modified Wild device, since the use thereof would have directly recorded the exhaust gas temperature at the engine exhaust.

Claims 35-36 and 45-46 is rejected under 35 U.S.C. 103(a) as being unpatentable over Wild et al. (Patent Number 6,352,065 B1), in view of Fujimoto et al. (Patent Number 4,485,625), in view of Mark's Standard Handbook for Mechanical Engineers (Tenth Edition, published in 1996 by McGraw Hill Companies).

Regarding claims 35 and 45, the modified Wild discloses the invention as recited above; however, fails to disclose the induction gas temperature is calculated in accordance with equation:

$$T_{ASG} = \frac{\dot{m}_{FG} T_{FG} C_{p,FG} + \dot{m}_{AG} T_{AG} C_{p,AG}}{\dot{m}_{FG} C_{p,FG} + \dot{m}_{AG} C_{p,AG}}$$

Mark's Standard Handbook for Mechanical Engineers teaches that it is conventional in the Thermodynamics, to derive the equation for calculating the induction gas temperature as being disclosed in claims 35 and 45 (See an attached copy of the part of Specific Heat of Mixtures on the section 4-4 Thermodynamics of Mark's Standard Handbook for Mechanical Engineers).

It would has been obvious to one having ordinary skill in the art at that time the invention was made, to have utilized this equation, as taught by Mark's Standard Handbook for Mechanical Engineers, to improve the efficiency of the modified Wild device; since the use thereof would have provided an accuracy in controlling of the induction temperature before being delivered into the engine.

Regarding claims 36 and 46, the modified Wild discloses the invention as recited above; however, fails to disclose the exhaust gas temperature at the heat exchanger outlet is calculated using the following equation system:

$$
\begin{aligned}
&|\Delta\dot{Q}_{KM}| = |\Delta\dot{Q}_{AG}| = \dot{Q}_{WT};\\
&\Delta\dot{Q}_{KM} = \dot{m}_{KM}C_{p,KM}(T_{KM,OUT} - T_{KM,IN});\\
&\Delta\dot{Q}_{AG} = \dot{m}_{AG}C_{p,AG}(T_{AG,IN} - T_{AG,OUT});\\
&\dot{Q}_{WT} = kA\Delta T_{m}
\end{aligned}
$$

Mark's Standard Handbook for Mechanical Engineers teaches that it is conventional in the Thermodynamics, to derive the equation for calculating the exhaust gas temperature at the heat exchanger outlet as being disclosed in claims 35 and 45 (See an attached copy of the part of Special Changes of State for Ideal Gases on the section 4-9 Thermodynamics of Mark's Standard Handbook for Mechanical Engineers).

It would has been obvious to one having ordinary skill in the art at that time the invention was made, to have utilized this equation, as taught by Mark's Standard Handbook for Mechanical Engineers, to improve the efficiency of the modified Wild device; since the use thereof would have provided an accuracy in controlling of the

exhaust gas temperature as well as in controlling the coolant flow through the heat exchanger.

Conclusion

The IDS (PTO-1449) filed on October 21, 2005 has been considered. An initialized copy is attached hereto.

The prior art made of record and not relied upon is considered pertinent to applicant's disclosure.

- Suzuki et al. (Pub. Number US 2007/0079607 A1) disclose an exhaust purifying for internal combustion engines.
- Ueno et al. (Pub. Number US 2007/0068159 A1) disclose a control system for internal combustion engines.
- Barbe et a l. (Pub. Number US 20070119172 A1) disclose a system and a method for diagnostic of low-pressure gas recirculation system and adapting of measurement devices.
- Moulin et al. (Pub. Number US 2005/0211233 A1) disclose a method for estimating the fuel/air ration in a cylinder of internal combustion engines.
- Schwulst et al. (US Patent Number 7,225,793 B2) disclose engine timing-control with an intake air pressure sensor.
- Nitzke et al. (US Patent Number 7,174,713 B2) disclose a method for determining of composition of the gas mixture in internal combustion engines.
- Fischer et al. (US Patent Number 7,174,777 B2) disclose a method for controlling at least one actuator in a mass flow duct.

- Atkins et al. (US Patent Number 7,127,892 B2) disclose techniques for determining turbocharger speeds.

- Nakazawa (US Patent Number 6,980,902 B2) discloses an estimation of intake gas temperature in internal combustion engines (See Figure 26).

- Kataoka et al. (US Patent Number 6,964,256 B2) disclose a combustion control apparatus for internal combustion engines.

- Bleile et al. (US Patent Number 6,952,640 B2) disclose a method and an arrangement for operating internal combustion engines.

- Reuschenbach et al. (US Patent Number 6,959,254 B2) disclose a method and a device for controlling and diagnosing a control system that influences a mass flow.

- Sun et al. (US Patent Number 6,866,030 B1) disclose a model based exhaust gas recirculation control algorithm.

- Kotwicki et al. (US Patent Number 6,738,707 B2) disclose a cylinder air charge estimation system and a method for controlling an internal combustion engine having exhaust gas recirculation system.

- Burgio et al. (US Patent Number 6,718,942 B2) disclose a method for estimation of the quantity of fresh air in the intake and exhaust manifolds.

- Kolmanovsky et al. (US Patent Number 6,651,492 B2) disclose a method and a system for controlling partial pressure of air in an intake manifold of an engine.

- Wild et al. (US Patent Number 6,588,261 B1) disclose a method for determining air entering the cylinders of an internal combustion engine having a supercharger.

- Matthews et al. (US Patent Number 5,273,019) disclose an apparatus with dynamic prediction of EGR in the intake manifold.

- Takahashi et al. (US Patent Number 5,205,260) disclose a method for detecting cylinder air amount introducing into cylinders of internal combustion engines.

- Pfitz (US Patent Number 5,941,927) discloses a method and an apparatus for determining the gas temperature in internal combustion engines.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Thai-Ba Trieu whose telephone number is (571) 272-4867. The examiner can normally be reached on Monday - Thursday (6:30-5:00).

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Thomas E. Denion can be reached on (571) 272-4859. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic

Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

TTB
June 28, 2007

Thaibatrieu

Thai-Ba Trieu
Primary Examiner
Art Unit 3748

and hydrogen gave a more accurate fit. A cubic polynomial in temperature was also fitted for more than 700 compounds from 273 to 1,000 K by Seres et al. in *Acta Phys. Chem.*, Univ. Szegediensis (Hungary), **23**, 1977, pp. 433–468. A 1975 formula of Wilhoit was fitted for 62 substances by A. Harmens in *Proc. Conf. Chemical Thermodynamic Data on Fluids*, IPC Sci. Tech. Press, Guildford, U.K., pp. 112–120. A cubic polynomial fitting for 435 substances appeared in *J. Chem. Eng., Peking*(**2**, 1979, pp. 109–132). The reader is reminded that specific heat at constant pressure values can readily be calculated from tabulated enthalpy-temperature tables, for any physical state. Table 4.2.22 gives values for liquids and gases, while Tables 4.2.27 to 4.2.29 provide similar information for selected solids.

SPECIFIC HEAT OF MIXTURES

If w_1 lb of a substance at temperature t_1 and with specific heat c_1 is mixed with w_2 lb of a second substance at temperature t_2 and with specific heat c_2, provided chemical reaction, heat evolution, or heat absorption does not occur, the specific heat of the mixture is

$$c_m = (w_1c_1 + w_2c_2)/(w_1 + w_2)$$

and the temperature of the mixture is

$$t_m = (w_1c_1t_1 + w_2c_2t_2)/(w_1c_1 + w_2c_2)$$

In general, $t_m = \Sigma wct/\Sigma wc$.

To raise the temperature of w_1 lb of a substance having a specific heat c_1 from t_1 to t_m, the weight w_2 of a second substance required is

$$w_2 = w_1c_1(t_m - t_1)/c_2(t_2 - t_m)$$

SPECIFIC HEAT OF SOLUTIONS

For aqueous solutions of salts, the specific heat may be estimated by assuming the specific heat of the solution equal to that of the water alone. Thus, for a 20 percent by weight solution of sodium chloride in water, the specific heat would be approximately 0.8.

Although approximate calculations of mixture properties often consist simply of multiplying the mole fraction of each constituent by the property of each constituent, more accurate calculations are possible. (See "Technical Data Book—Petroleum Refining" API, Washington, DC, 1984; Daubert, "Chemical Engineering Thermodynamics," McGraw-Hill; "The Properties of Gases and Liquids," 3d ed., McGraw-Hill; Perry, "Chemical Engineers Handbook," McGraw-Hill; Walas, "Phase Equilibria in Chemical Engineering," Butterworth.)

LATENT HEAT

For pure substances, the heat effects accompanying changes in state at constant pressure are known as latent effects, because no temperature change is evident. Heat of fusion, vaporization, sublimation, and change in crystal form are examples.

The values for the heat of fusion and latent heat of vaporization are presented in Tables 4.2.21 and 4.2.28.

GENERAL PRINCIPLES OF THERMODYNAMICS

Notation

B = availability (by definition, $B = H - T_oS$)
c_p = specific heat at constant pressure
c_v = specific heat at constant volume
E, e = total energy associated with system
g = local acceleration of gravity, ft/s²
g_c = a dimensional constant
H, h = enthalpy, Btu (by definition $h = u + pv$)
J = mechanical equivalent of heat = 778.26 ft·lb/Btu = 4.1861 J/cal
$k = c_p/c_v$
m = mass of substance under consideration, lbm
M = molecular weight
p = absolute pressure, lb/ft²
Q, q = quantity of heat absorbed by system from surroundings, Btu
R = ideal gas constant
R_u = universal gas constant
S, s = entropy
t = temperature, °F
$T = t + 459.69$ = absolute temperature = °R
T_0 = sink or discard temperature
U, u = internal energy
$\bar{v}$ = linear velocity
v = volume
V = total volume
w = weight of substance under consideration, lb
W = external work performed on surroundings during change of state, ft·lb
$Y = \left(\dfrac{p_1}{p_2}\right)^{(k-1)k} - 1$
z = distance above or below chosen datum
g = free energy (by definition, $g = h - Ts$)
f = Helmholtz free energy (by definition, $f = u - Ts$)

In thermodynamics, unless otherwise noted, the convention followed is that the change in any property $\psi = \Delta\psi$ = final value − initial value = $\psi_2 - \psi_1$.

In this notation, small letters usually denote magnitudes referred to a unit mass of the substance, capital letters corresponding magnitudes referred to m units of mass. Thus, v denotes the volume of 1 lb, and $V = mv$, the volume of m lb. Similarly, $U = mu$, $S = ms$, etc. Subscripts are used to indicate different states; thus, p_1, v_1, T_1, u_1, s_1 refer to state 1; p_2, v_2, T_2, u_2, s_2 refer to state 2; Q_{12} is used to denote the heat transferred during the change from state 1 to state 2, and W_{12} denotes the external work done during the same change.

Thermodynamics is the study which deals with energy, the various concepts and laws describing the conversion of one form of energy to another, and the various systems employed to effect the conversions. Thermodynamics deals in general with systems in equilibrium. By means of its fundamental concepts and basic laws, the behavior of an engineering system may be described when the various variables are altered. Thermodynamics covers a very broad field and includes many systems, for example, those dealing with chemical, thermal, mechanical, and electrical force fields and potentials. The quantity of matter within a prescribed boundary under consideration is called the **system**, and everything external to the system is spoken of as the **surroundings**. With a **closed system** there is no interchange of matter between system and surroundings; with an **open system** there is such an interchange. Any change that the system may undergo is known as a **process**. Any process or series of processes in which the system returns to its original condition or state is called a **cycle**.

Heat is energy **in transit** from one mass to another because of a temperature difference between the two. Whenever a force of any kind acts through a distance, **work** is done. Like heat, work is also energy in transit. Work is to be differentiated from the capacity of a quantity of energy to do work.

The two fundamental and general laws of thermodynamics are: (1) energy may be neither created nor destroyed, (2) it is impossible to bring about any change or series of changes the sole net result of which is transfer of energy as heat from a low to a high temperature; in other words, heat will not of itself flow from low to high temperatures.

The **first law of thermodynamics**, one of the very important laws of nature, is the law of conservation of energy. Although the law has been stated in a variety of ways, all have essentially the same meaning. The following are examples of typical statements: Whenever energy is transformed from one form to another, energy is always conserved; energy can neither be created nor destroyed; the sum total of all energy remains constant. The energy conservation hypothesis was stated by a number of investigators; however, experimental evidence was not available until the famous work of J. P. Joule. Transformation of matter

very complex. Experience has demonstrated that a mixture of gases may be regarded as an equivalent gas, the properties of which depend upon the kind and proportion of each of the constituents. The general relations applicable to a mixture of perfect gases will be presented. Let V denote the total volume of the mixture, $m_1, m_2, m_3, \ldots$ the masses of the constituent gases, $R_1, R_2, R_3, \ldots$ the corresponding gas constants, and R_m the constant for the mixture. The **partial pressures** of the constituents, i.e., the pressures that the constituents would have if occupying the total volume V, are $p_1 = m_1R_1T/V$, $p_2 = m_2R_2T/V$, etc.

According to Dalton's law, the **total pressure p of the mixture** is the sum of the partial pressures; i.e., $p = p_1 + p_2 + p_3 + \cdots$. Let $m' = m_1 + m_2 + m_3 + \cdots$ denote the total mass of the mixture; then $pV = mR_mT$ and $R_m = \Sigma(m_iR_i)/m$. Also $p_1/p = m_1R_1/(mR_m)$, $p_2/p = m_2R_2/(mR_m)$, etc.

Let $V_1, V_2, V_3 + \ldots$ denote the volumes that would be occupied by the constituents at pressure p and temperature T (these are given by the volume composition of the gas). Then $V = V_1 + V_2 + V_3 + \cdots$ and the apparent molecular weight m_m of the mixture is $m_m = \Sigma(m_iV_i)/V$. Then $R_m = 1{,}546/m_m$. The subscript i denotes an individual constituent.

Volume of 1 lb at 32°F and atm pressure $= 359/m_m$.

Mass of 1 ft³ at 32°F and atm pressure $= 0.002788m_m$.

The specific **heats of the mixture** are, respectively,

$$c_p = \Sigma(m_ic_{pi})/m \qquad c_v = \Sigma(m_ic_{vi})/m$$

Internal Energy, Enthalpy, and Entropy of an Ideal Gas If an ideal gas with constant specific heats changes from an initial state p_1, V_1, T_1 to a final state p_2, V_2, T_2, the following equations hold:

$$u_2 - u_1 = mc_v(T_2 - T_1) = (p_2v_2 - p_1v_1)(k - 1)$$

$$h_2 - h_1 = mc_p(T_2 - T_1) = k\,\frac{(p_2v_2 - p_1v_1)}{k - 1}$$

$$s_2 - s_1 = m\left(c_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}\right)$$

$$= m\left(c_p \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1}\right) = m\left(c_p \ln \frac{v_2}{v_1} + c_v \ln \frac{p_2}{p_1}\right)$$

In general, the energy per unit mass is $u = c_vT + u_0$, the enthalpy is $h = c_pT + h_0$, and the entropy is $s = c_v \ln T + R \ln v + s_0 = c_p \ln T - R \ln p + s_0' = c_p \ln v + c_p \ln p = s_0''$.

The two fundamental equations for ideal gases are

$$dq = c_v\,dT + p\,dv \qquad dq = c_p\,dT - v\,dp$$

SPECIAL CHANGES OF STATE FOR IDEAL GASES

(Specific heats assumed constant)

In the following formulas, the subscripts 1 and 2 refer to the initial and final states, respectively.

1. *Constant volume:* $p_2/p_1 = T_2/T_1$.

$$Q_{12} = U_2 - U_1 = mc_v(t_2 - t_1) = V(p_2 - p_1)/(k - 1)$$
$$W_{12} = 0 \qquad s_2 - s_1 = mc_v \ln (T_2/T_1)$$

2. *Constant pressure:* $V_2/V_1 = T_2/T_1$.

$$W_{12} = -p(V_2 - V_1) = -mR(t_2 - t_1)$$
$$Q_{12} = mc_p(t_2 - t_1) = kW_{12}/(k - 1)$$
$$s_2 - s_1 = mc_p \ln(T_2/T_1)$$

3. *Isothermal (constant temperature):* $p_2/p_1 = V_1/V_2$.

$$U_2 - U_1 = 0 \qquad W_{12} = -mRT \ln (V_2/V_1) = -p_1V_1 \ln (V_2/V_1)$$
$$Q_{12} = -W_{12} \qquad s_2 - s_1 = Q_{12}/T = mR \ln (V_2/V_1)$$

4. *Reversible adiabatic, isentropic:* $p_1V_1^k = p_2V_2^k$.

$$T_2/T_1 = (V_1/V_2)^{k-1} = (p_2/p_1)^{(k-1)/k}$$
$$W_{12} = U_1 - U_2 = mc_v(t_1 - t_2)$$
$$Q_{12} = 0 \qquad s_2 - s_1 = 0$$
$$W_{12} = (p_2V_2 - p_1V_1)/(k - 1)$$
$$= -p_1V_1\,[(p_2/p_1)^{(k-1)/k} - 1]/(k - 1)$$

5. *Polytropic:* This name is given to the change of state which is represented by the equation $pV^n = \text{const}$. A polytropic curve usually represents actual expansion and compression curves in motors and air compressors for pressures up to a few hundred pounds. By giving n different values and assuming specific heats constant, the preceding changes may be made special cases of the polytropic change, thus,

For $n = 1$,	$pv = \text{const}$	isothermal
$n = k$,	$pv^k = \text{const}$	isentropic
$n = 0$,	$p = \text{const}$	constant pressure
$n = \infty$,	$v = \text{const}$	constant volume

For a polytropic change of an ideal gas (for which c_v is constant), the specific heat is given by the relation $c_n = c_v(n - k)(n - 1)$; hence for $1 < n < k$, c_n is negative. This is approximately the case in air compression up to a few hundred pounds pressure. The following are the principal formulas:

$$p_1V_1^n = p_2V_2^n$$
$$T_2/T_1 = (V_1/V_2)^{n-1} = (p_2/p_1)^{(n-1)/n}$$
$$W_{12} = (p_2V_2 - p_1V_1)/(n - 1)$$
$$= -p_1V_1\,[(p_2/p_1)^{(n-1)/n} - 1]/(n - 1)$$
$$Q_{12} = mc_n(t_2 - t_1)$$
$$W_{12} : U_2 - U_1 : Q_{12} = k - 1 : 1 - n : k - n$$

The quantity $(p_2/p_1)^{(k-1)/k} - 1$ occurs frequently in calculations for perfect gases.

Determination of Exponent n If two representative points (p_1, V_1 and p_2, V_2) be chosen, then

$$n = (\log p_1 - \log p_2)/(\log V_2 - \log V_1)$$

Several pairs of points should be used to test the constancy of n.

Changes of State with Variable Specific Heat In case of a considerable range of temperature, the assumption of constant specific heat is not permissible, and the equations referring to changes of state must be suitably modified. (This statement does not apply to inert or monatomic gases.) Experiments on the specific heat of various gases show that the specific heat may sometimes be taken as a linear function of the temperature: thus, $c_v = a + bT$; $c_p = a' + b'T$. In that case, the following expressions apply for the change of internal energy and entropy, respectively:

$$U_2 - U_1 = m[a(T_2 - T_1) + 0.5b(T_2^2 - T_1^2)]$$
$$S_2 - S_1 = m[a \ln (T_2/T_1) + b(T_2 - T_1) + R \ln (V_2/V_1)]$$

and for an isentropic change,

$$W_{12} = U_2 - U_1$$
$$R \ln (V_1/V_2) = a \ln (T_2/T_1) + b(T_2 - T_1)$$

GRAPHICAL REPRESENTATION

The change of state of a substance may be shown graphically by taking any two of the six variables p, V, T, S, U, H as independent coordinates and drawing a curve to represent the successive values of these two variables as the change proceeds. While any pair may be chosen, there are three systems of graphical representation that are specially useful.

1. p and V. The curve (Fig. 4.1.4) represents the simultaneous values of p and V during the change (reversible) from state 1 to state

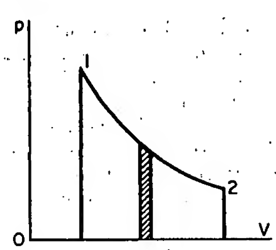

Fig. 4.1.4